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(54) **ELECTRONIC DEVICE, AND CAPACITOR CAPACITANCE DETECTION METHOD APPLIED TO THE SAME**

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(51) **Int. Cl.**

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**G01D 5/24** (2006.01)  
**G06K 9/00** (2006.01)

**ABSTRACT**

According to one embodiment, an electronic device includes a capacitor, a power supply device, a discharger and a capacitance detector. The capacitor is used as a backup power supply. The power supply device charges the capacitor. The discharger discharges the capacitor. The capacitance detector maintains a terminal voltage of the capacitor at a given level for a predetermined time, by controlling an operating time of the power supply device. The capacitance detector allows the discharger to start the discharge the predetermined time later. The capacitance detector detects a capacitance of the capacitor based on a transient response characteristic of the discharge.

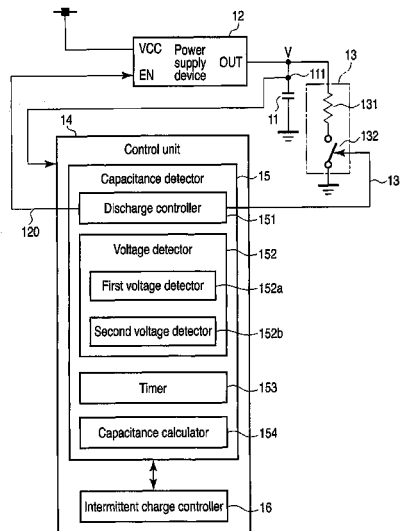
(52) **U.S. Cl.**

CPC ..... **G01R 27/2605** (2013.01); **G01D 5/24** (2013.01); **G06K 9/0002** (2013.01); **G01R 27/26** (2013.01)

(58) **Field of Classification Search**

CPC ..... G01R 27/2605; G01R 27/26; G01D 5/24; G06K 9/0002  
USPC ..... 324/658, 649, 600, 678, 548, 519  
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**20 Claims, 6 Drawing Sheets**



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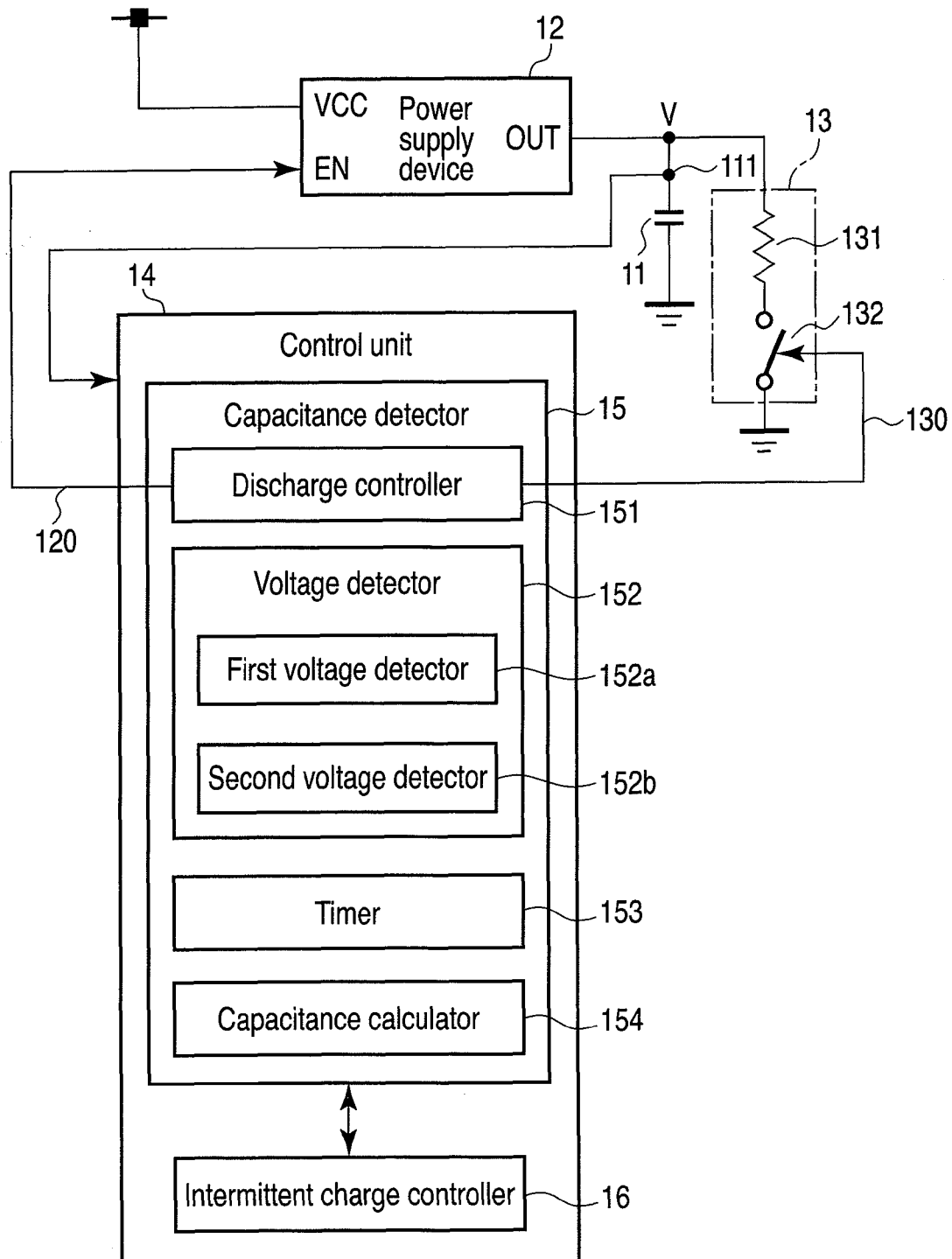


FIG. 1

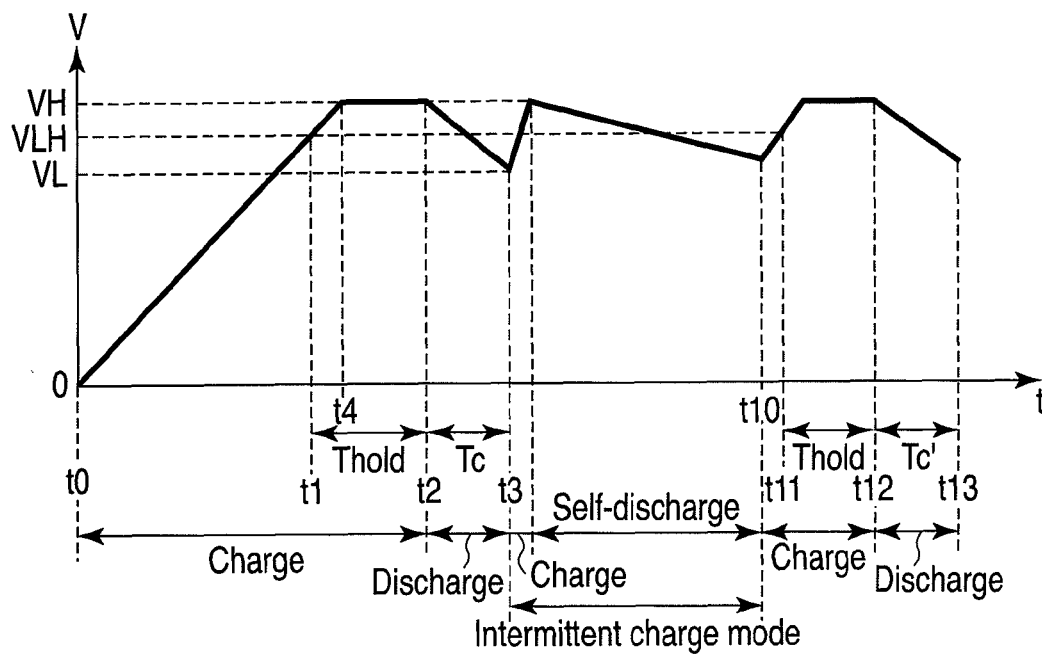


FIG. 2

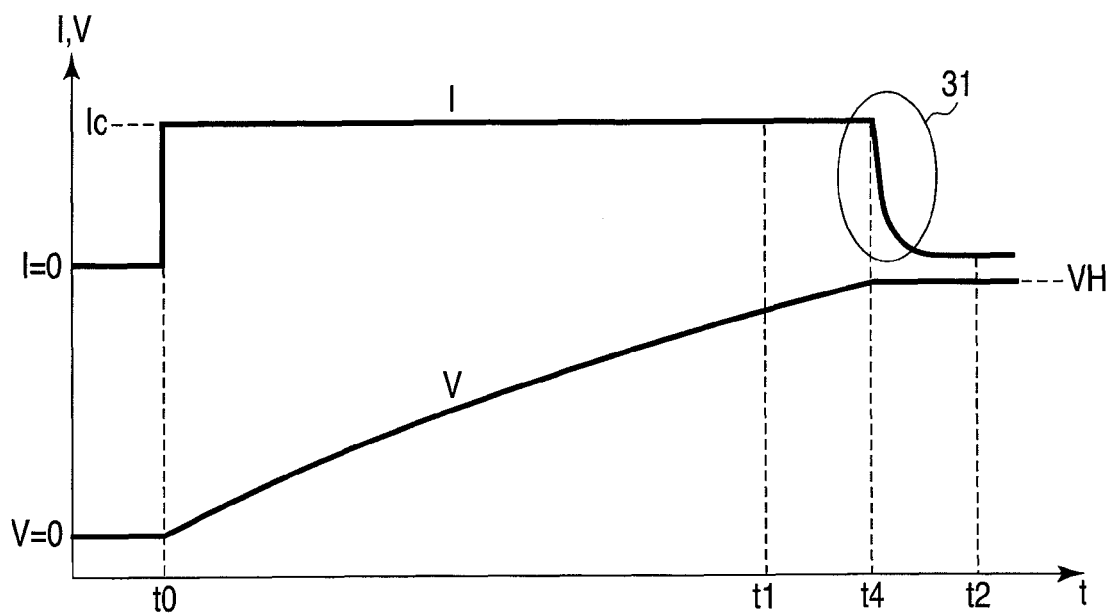


FIG. 3

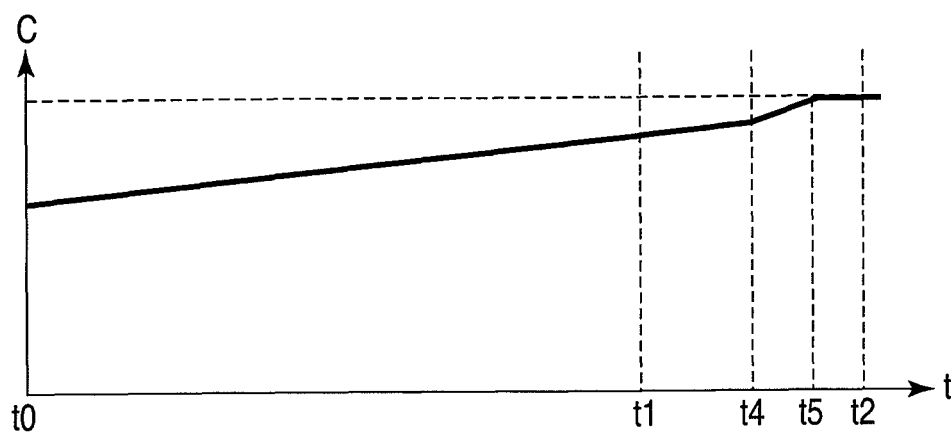


FIG. 4

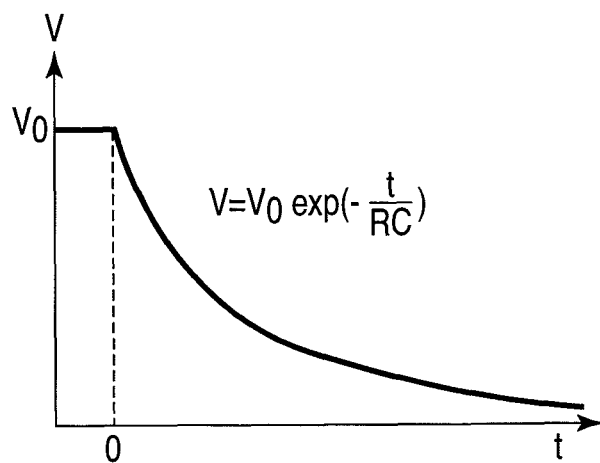


FIG. 5

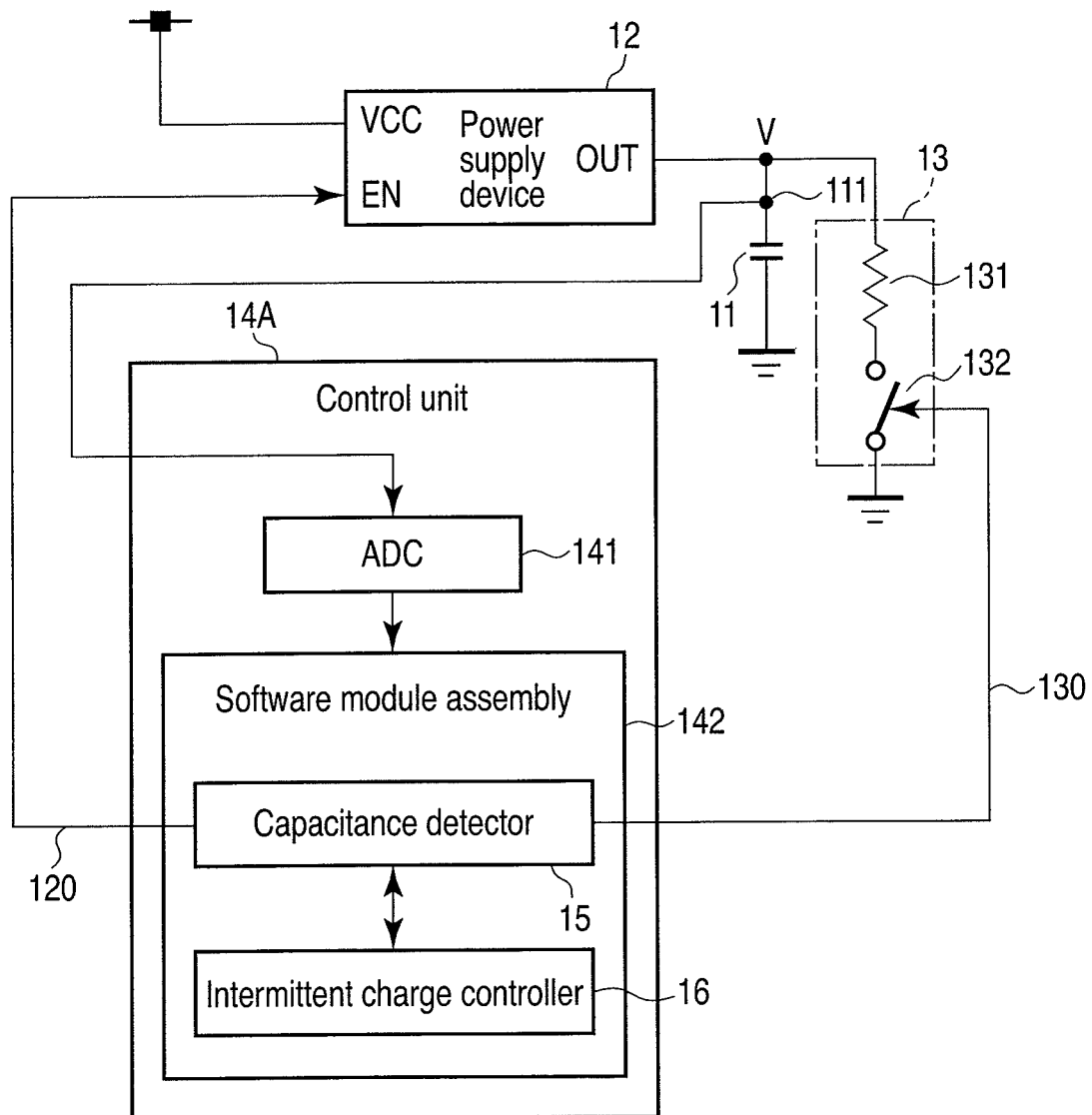


FIG. 6

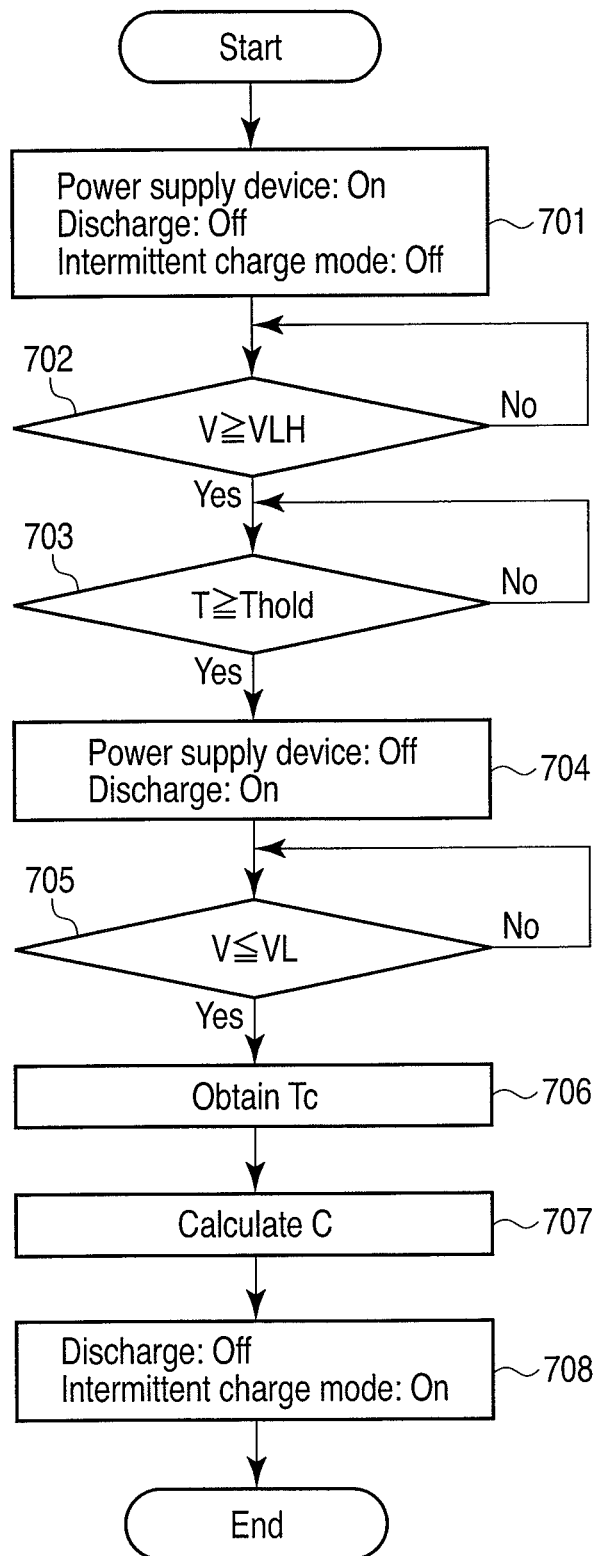


FIG. 7

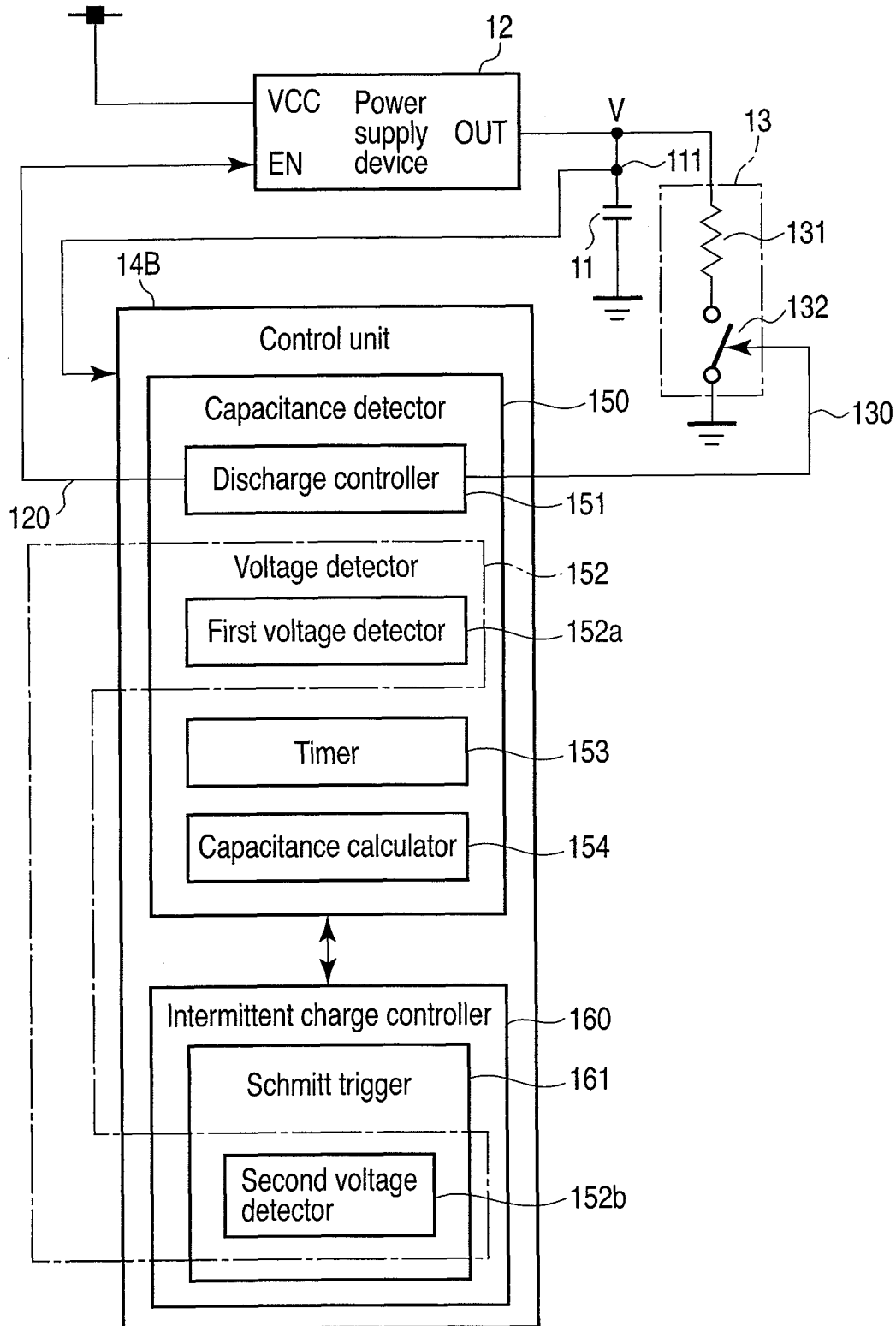


FIG. 8



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# ELECTRONIC DEVICE, AND CAPACITOR CAPACITANCE DETECTION METHOD APPLIED TO THE SAME

## CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims the benefit of priority from prior Japanese Patent Application No. 2010-288832, filed Dec. 24, 2010, the entire contents of which are incorporated herein by reference.

## FIELD

Embodiments described herein relate generally to an electronic device having a capacitor, and a capacitor capacitance detection method applied to the electronic device.

## BACKGROUND

Recently emerging types of electronic devices such as solid-state drives (SSDs) comprise a backup power supply. A capacitor of an electric double layer type is commonly used as such a backup power supply.

Degradation of a capacitor appears as a change in the capacitance of the capacitor. Thus, it is known that the capacitance of the capacitor is detected in order to predict possible rapid degradation of the capacitor. It is also known that the capacitance of the capacitor is detected (or measured) by utilizing transient response characteristics observed when the charge stored in the capacitor is discharged.

The recent electronic devices having a capacitor as a backup power supply provide an intermittent charging control function to intermittently charge the capacitor in order to prevent possible overcharging that may cause the capacitor to be degraded. Immediately after charging or with the capacitor intermittently charged, a voltage applied to the capacitor (that is, the terminal voltage of the capacitor) is not constant. In such a state, the capacitance of the capacitor is not saturated. Thus, accurately detecting the capacitance utilizing the transient response characteristics is difficult.

## BRIEF DESCRIPTION OF THE DRAWINGS

A general architecture that implements the various features of the embodiments will now be described with reference to the drawings. The drawings and the associated descriptions are provided to illustrate the embodiments and not to limit the scope of the invention.

FIG. 1 is a block diagram showing an exemplary configuration of an electronic device according to a first embodiment;

FIG. 2 is a voltage waveform diagram illustrating an exemplary relationship between the terminal voltage of the capacitor and time, wherein the terminal voltage is measured at the time of detection of the capacitance of the capacitor and before and after the detection;

FIG. 3 is a waveform diagram illustrating an exemplary relationship between time and a charge current used to charge the capacitor and an exemplary relationship between the terminal voltage of the capacitor and time;

FIG. 4 is a diagram illustrating an exemplary state in which the capacitance of the capacitor stabilizes as time elapses if the charge current and the terminal voltage vary as shown in FIG. 3;

FIG. 5 is a waveform diagram illustrating an exemplary relationship between time and the terminal voltage of the capacitor obtained during transient response of the capacitor;

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FIG. 6 is a block diagram showing an exemplary configuration of an electronic device according to a second embodiment;

FIG. 7 is a flowchart illustrating an exemplary procedure for detecting the capacitance of a capacitor which procedure is applied in the second embodiment; and

FIG. 8 is a block diagram showing an exemplary configuration of an electronic device according to a third embodiment.

## DETAILED DESCRIPTION

Various embodiments will be described hereinafter with reference to the accompanying drawings.

In general, according to one embodiment, an electronic device comprises a capacitor, a power supply device, a discharger and a capacitance detector. The capacitor is configured to be used as a backup power supply. The power supply device is configured to charge the capacitor. The discharger is configured to discharge the capacitor. The capacitance detector is configured to maintain a terminal voltage of the capacitor at a given level for a predetermined time, by controlling an operating time of the power supply device. The capacitance detector is configured to allow the discharger to start the discharge the predetermined time later. The capacitance detector is configured to detect a capacitance of the capacitor based on a transient response characteristic of the discharge. [First Embodiment]

FIG. 1 is a block diagram showing an exemplary configuration of an electronic device according to a first embodiment. In the first embodiment, the electronic device illustrated in FIG. 1 is assumed to be a solid-state drive (SSD). However, the electronic device illustrated in FIG. 1 may be a hard disk drive (HDD). Alternatively, the electronic device illustrated in FIG. 1 may be an electronic device different from the electronic device such as an SSD or HDD.

The electronic device illustrated in FIG. 1 comprises a capacitor 11, a power supply device 12, a discharger 13, and a control unit 14. The capacitor 11 is used as a backup power supply for the electronic device illustrated in FIG. 1. The capacitor 11 is of, for example, an electric double layer type. However, capacitor 11 need not be of the electric double layer type.

While enabled, the power supply device 12 charges the capacitor 11. The power supply device 12 comprises an enable terminal EN to which an enable signal 120 from the control unit 14 is input. The power supply device 12 is set enabled while the enable signal 120 is asserted. The power supply device 12 is of, for example, a constant-voltage constant-current (CVCC) type. In an initial stage of charging, the power supply device 12 performs constant-current control to supply a constant current  $I_c$  to the capacitor 11. When the capacitor 11 is sufficiently charged for at least a predetermined time, the terminal voltage  $V$  of the capacitor 11 reaches a constant voltage  $V_H$ . In this state, the power supply device 12 shifts to constant-voltage control. The constant voltage  $V_H$  is also referred to as the first voltage  $V_H$  or simply voltage  $V_H$ .

The discharger 13 is used to detect the capacitance of the capacitor 11. The discharger 13 discharges the capacitor 11. That is, the discharger 13 emits charge accumulated in the capacitor 11. The discharger 13 comprises a resistor 131 and a switch 132. The resistor 131 and the switch 132 are connected in series with one end 111 of the capacitor 11. The resistor 131 has a given resistance  $R$ . The switch 132 is turned on and off in accordance with a control signal 130 from a discharge controller 151 in the control unit 14 which will be

described below. The switch **132** is of, for example, a field-effect transistor (FET) type. However, the switch **132** need not be of the FET type.

The control unit **14** controls each section in the electronic device. The control unit **14** comprises a capacitance detector **15** and an intermittent charge controller **16**. The capacitance detector **15** detects the capacitance  $C$  of the capacitor **11**. The capacitance detector **15** comprises a discharge controller **151**, a voltage detector **152**, a timer **153**, and a capacitance calculator **154**.

When the capacitance of the capacitor **11** is detected, the discharge controller **151** sets the discharger **13** (more specifically, the switch **132** in the discharger **13**) to an on state to allow the discharger **13** to start discharging the capacitor **11**. The discharger **13** (more specifically, the switch **132** in the discharger **13**) is set in the on state while the discharge controller **151** is asserting the control signal **130**. The discharge controller **151** asserts the control signal **130** if a predetermined period  $T_{hold}$  elapses from the time when the terminal voltage  $V$  of the capacitor **11** reaches a voltage  $V_{LH}$  (second voltage) or higher.  $V_{LH}$  is lower than voltage  $V_H$  (first voltage) and higher than a voltage  $V_L$  (third voltage) described below. That is,  $V_L < V_{LH} < V_H$ . More specifically, in the present embodiment, detection of  $V_{LH}$  is carried out to pre-detect that the terminal voltage  $V$  has reached  $V_H$  and is then to be kept at  $V_H$ . Thus,  $V_{LH}$  is set smaller than  $V_H$  by a predetermined amount  $\Delta V$  and higher than  $V_L$ . That is,  $V_L < V_{LH} (=V_H - \Delta V) < V_H$ .

The discharge controller **151** also negates the control signal **130** if the terminal voltage  $V$  reaches  $V_L$  or lower while the control signal **130** is being asserted. In the first embodiment, the discharge controller **151** is assumed to be, for example, a functional module (that is, a software module) implemented when a microprocessor reads and executes a control program (hereinafter referred to as firmware) stored in a program memory. However, the discharge controller **151** may comprise a hardware module.

The voltage detector **152** comprises a first voltage detector **152a** and a second voltage detector **152b**. The first voltage detector **152a** detects that the terminal voltage  $V$  of the capacitor **11** has reached  $V_{LH}$  or higher. In the first embodiment, the first voltage detector **152a** is a hardware module and is, for example, a comparator configured to compare the terminal voltage  $V$  with  $V_{LH}$ , which serves as a reference voltage. The second voltage detector **152b** detects that the terminal voltage  $V$  of the capacitor **11** has reached  $V_L$  or lower. In the first embodiment, the second voltage detector **152b** is a hardware module and is, for example, a comparator configured to compare the terminal voltage  $V$  with  $V_L$ , which serves as a reference voltage. However, the first voltage detector **152a** and the second voltage detector **152b** may comprise software modules.

The timer **153** measures the predetermined period  $T_{hold}$  from the time when the detector detects that the terminal voltage  $V$  of the capacitor **11** has reached  $V_{LH}$  or higher. The timer **153** also measures a period  $T_c$  for which the control signal **130** has been asserted. That is, the timer **153** also measures period  $T_c$  from the completion of measurement of period  $T_{hold}$  until the detector detects that the terminal voltage  $V$  of the capacitor **11** has reached  $V_L$  or lower. In the first embodiment, the timer **153** is a hardware timer. However, the timer **153** may be a software timer. The capacitance calculator **154** calculates (detects) the capacitance of the capacitor **11** based on the measured period  $T_c$ . In the first embodiment, the capacitance calculator **154** is a software module. However, the capacitance calculator **154** may be a hardware module.

The intermittent charge controller **16** has a well-known intermittent charge control function to intermittently charge the capacitor **11**. The intermittent charge controller **16** is enabled when set to an intermittent charge mode. The intermittent charge controller **16** performs intermittent charge control to prevent possible overcharging that may cause the capacitor **11** to be degraded. This enables the life of the capacitor **11** to be prolonged. In the first embodiment, the intermittent charge controller **16** is a hardware module comprising a well-known Schmitt trigger. However, the intermittent charge controller **16** may be a software module.

Now, the operation of the first embodiment will be described with reference to FIG. 2 taking as an example a case where the capacitance  $C$  of the capacitor **11** is detected. FIG. 2 is a voltage waveform diagram illustrating the relationship between the terminal voltage  $V$  of the capacitor **11** and time; the terminal voltage is measured at the time of detection of the capacitance  $C$  of the capacitor **11** and before and after the detection.

First, it is assumed that at time  $t_0$ , the discharge controller **151** of the capacitance detector **15** asserts the enable signal **120**, negates the control signal **130**, and sets the intermittent charge mode to an off state. The power supply device **12** is set enabled (on state) when the enable signal **120** is asserted. Thus, the power supply device **12** operates based on a power supply voltage  $V_{CC}$  applied by a main power supply (not shown in the drawings) for the electronic device. More specifically, the power supply device **12** operates as a constant-voltage constant-current power supply for charging the capacitor **11** within the preset ranges of the voltage and the current, depending on the state of the capacitor **11** (that is, a load state). During an initial period of charging, the power supply device **12** supplies the capacitor **11** with the constant current  $I_c$ . Thus, the terminal voltage  $V$  of the capacitor **11** rises as shown in FIG. 2.

It is assumed that the terminal voltage  $V$  subsequently reaches voltage  $V_{LH}$  at time  $t_1$ . Then, the first voltage detector **152a** detects that the terminal voltage  $V$  has reached  $V_{LH}$  or higher. The timer **153** measures period  $T_{hold}$  elapsing from time  $t_1$  when the detector detects that terminal voltage  $V$  has reached  $V_{LH}$  or higher. Even during period  $T_{hold}$ , the terminal voltage  $V$  is raised based on the constant current control performed by the power supply device **12**. At this time, the intermittent charge controller **16** is not set to the intermittent charge mode. Thus, the intermittent charge control is disabled (or stopped). That is, the intermittent charge control intended for the capacitor **11** is inhibited. Hence, upon reaching voltage  $V_H$  at time  $t_4$ , the terminal voltage  $V$  of the capacitor **11** is maintained at  $V_H$  based on the constant voltage control performed by the power supply device **12**.

Period  $T_{hold}$  is set to be sufficient to maintain the terminal voltage  $V$  at  $V_H$ . During the initial part of period  $T_{hold}$ , the terminal voltage rises from  $V_{LH}$  to  $V_H$ . However, during the remaining part of period  $T_{hold}$ , the terminal voltage  $V$  is maintained at  $V_H$ . That is, the terminal voltage  $V$  is ensured to be maintained at  $V_H$  during period  $T_{hold}$ . Thus, the state of the terminal voltage  $V$  during period  $T_{hold}$  is expressed as the state in which the terminal voltage  $V$  is maintained at a given level. Furthermore, an operation of charging the capacitor **11** during period  $T_{hold}$  is hereinafter referred to as precharging (more specifically, precharging for detecting the capacitance  $C$  of the capacitor **11**).

FIG. 3 is a waveform diagram illustrating the relationship between time  $t$  and a charge current  $I$  used to charge the capacitor **11** and the relationship between the terminal voltage  $V$  of the capacitor **11** and time  $t$ . As is apparent from FIG. 3, during the initial period of charging (the period from  $t_0$  to

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$t_4$ ), when the terminal voltage  $V$  rises, the constant current control is performed by the function of the power supply device **12** serving as a constant-voltage constant-current power supply. Thus, the charge current  $I$  is constant and equal to the constant current  $I_c$ . When the terminal voltage  $V$  reaches  $V_H$ , the predetermined constant voltage, at time  $t_4$ , the power supply device **12** shifts to the constant voltage control.

However, immediately after time  $t_4$ , when the power supply device **12** shifts to the constant voltage control, the charge current  $I$  decreases slowly as shown within an elliptical outline **31** in FIG. **3**. This is because as a result of the function of the power supply device **12** serving as a constant-voltage constant-current power supply, the terminal voltage  $V$  is constant ( $V_H$ ), whereas the capacitance  $C$  of the capacitor **11** rises slowly. After the power supply device **12** shifts to the constant voltage control, the relationship between the capacitance  $C$  and the current  $I$  follows the case where  $dV/dt$  corresponding to  $V$  of Equation 10 is 0, as described below. After the power supply device **12** shifts to the constant voltage control, the capacitance  $C$  slowly settles down to a constant value as time  $t$  elapses. FIG. **4** illustrates how the capacitance  $C$  stabilizes as time  $t$  elapses if the charge current  $I$  and the terminal voltage  $V$  vary as shown in FIG. **3**.

As described above, a slight amount of time is required to stabilize the capacitance  $C$  of the capacitor **11**. If the capacitor **11** is discharged and the capacitance  $C$  is detected utilizing transient response characteristics before the capacitance  $C$  is stabilized, accurately detecting the capacitance  $C$  is difficult as described below. Thus, the discharge controller **151** sufficiently carries out precharging so as to stabilize the capacitance of the capacitor **11** (so as to stabilize the terminal voltage  $V$  of the capacitor **11** at the predetermined voltage ( $V_H$ )) before the capacitor **11** is discharged. In the example illustrated in FIG. **2** and FIG. **3**, the terminal voltage  $V$  at time  $t_0$  is zero. However, the terminal voltage  $V$  at time  $t_0$  is not necessarily zero.

It is assumed that the timer **153** finishes measuring period  $T_{\text{hold}}$  at time  $t_2$  ( $t_2 > t_4$ ) shown in FIG. **2**. At time  $t_2$ , the discharge controller **151** negates the enable signal **120** and asserts the control signal **130**. Thus, the switch **132** of the discharger **13** is turned on. Then, the charge accumulated in the capacitor **11** is emitted via the resistor **131** of the discharger **13**. That is, the current  $I$  flows from the capacitor **11** to the resistor **131**. The timer **153** starts measuring the time again at time  $t_2$ .

When the capacitor **11** is discharged, the terminal voltage  $V$  of the capacitor **11** decreases as shown in FIG. **2**. It is assumed that the terminal voltage  $V$  subsequently reaches voltage  $V_L$  at time  $t_3$ . Then, the second voltage detector **152b** detects that the terminal voltage  $V$  has reached  $V_L$  or lower. The timer **153** measures period  $T_c$  from time  $t_2$  to time  $t_3$ . At time  $t_3$ , the detector detects that the terminal voltage  $V$  has reached  $V_L$  or lower.

The capacitance calculator **154** calculates the capacitance  $C$  of the capacitor **11** based on the measured period  $T_c$ . The calculation of the capacitance  $C$  carried out by the capacitance calculator **154** will be described below in detail. First, it is assumed that the terminal voltage  $V$  of the capacitor **11** is  $V_0$  when the capacitor **11** is sufficiently charged. In this state, when the capacitor **11** is discharged via the discharger **13**, the terminal voltage  $V$  of the capacitor **11** falls in accordance with Equation 1 expressing a transient response.

$$V = V_0 \exp(-t/RC) \quad (1)$$

In Equation 1,  $V_0$  denotes the terminal voltage  $V$  of the capacitor **11** obtained when discharge is started, that is, the initial value of  $V$  in the transient response.  $R$  denotes the resistance of the resistor **131**.  $C$  denotes the capacitance of the capacitor **11**. Furthermore,  $t$  denotes the elapsed time from

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the beginning of discharge (that is, the transient response time). FIG. **5** is a waveform diagram illustrating the relationship between the time and the terminal voltage obtained during the transient response.

As is apparent from Equation 1, the equation allows the capacitance  $C$  of the capacitor **11** to be calculated. In the first embodiment, the capacitance calculator **154** calculates the capacitance  $C$  in accordance with Equation 1 based on period  $T_c$  from time  $t_2$ , when discharge is started, to time  $t_3$ , when the terminal voltage  $V$  reaches  $V_L$  or lower. In this case, the capacitance calculator **154** uses  $V_H$ ,  $V_L$ , and  $T_c$  as  $V_0$  (initial voltage),  $V$  (the voltage obtained when the capacitance is detected), and  $t$  (transient response time), respectively.

That is, the capacitance calculator **154** calculates the capacitance  $C$  in accordance with Equation 2.

$$V_L = V_H \exp(-T_c/RC) \quad (2)$$

Based on Equation 2, the capacitance  $C$  is expressed by Equation 3.

$$C = -T_c/R(1/\ln(V_L/V_H)) \quad (3)$$

As is apparent from Equation 3, the capacitance calculator **154** calculates the capacitance  $C$  based on the measured period  $T_c$ , the resistance  $R$  of the resistor **131** of the discharger **13**, voltage  $V_H$ , and voltage  $V_L$ . Here, the elements other than period  $T_c$ , that is,  $R$ ,  $V_H$ , and  $V_L$  are predetermined. The capacitance detector **15** can determine the life of the capacitor **11** based on the capacitance  $C$  calculated by the capacitance calculator **154**.

Here, unlike in the first embodiment, the capacitance  $C$  is calculated based on, for example, discharging the capacitor **11** at time  $t_4$ , when the terminal voltage  $V$  reaches voltage  $V_H$  as shown in FIG. **2**. In this case, accurately detecting the capacitance  $C$  is difficult as described below.

First, such a relationship as expressed by Equation 4 exists between the charge  $Q(t)$ , capacitance  $C(t)$ , and terminal voltage  $V(t)$  of the capacitor **11** at a given time  $t$ .

$$Q(t) = C(t)V(t) \quad (4)$$

Differentiating both sides of Equation 3 with respect to  $t$  results in Equation 5.

$$dQ(t)/dt = C(t) \partial V(t) / \partial t + V(t) \partial C(t) / \partial t \quad (5)$$

Between times  $t_0$  and  $t_1$  shown in FIG. **2**, the second term of the right side of Equation 5 makes only insignificant contribution. Thus, Equation 5 is approximated by Equation 6.

$$dQ(t)/dt = C(t) dV(t)/dt \quad (6)$$

Then, between times  $t_4$  and  $t_2$  shown in FIG. **2**, voltage  $V$  is almost constant. Thus, when the current supplied to the capacitor **11** at time  $t$  is denoted by  $I(t)$ , Equation 5 is approximated by Equation 7.

$$\begin{aligned} dQ(t)/dt &= V(t) dC(t)/dt \\ &= I(t) \end{aligned} \quad (7)$$

Equation 7 can be transformed into Equation 8.

$$dC(t)/dt = I(t)/V(t) \quad (8)$$

Both sides of Equation 8 are integrated over the period from time  $t_4$  to time  $t_2$  as expressed by Equation 9.

$$\int_{t_4-t_2} \{dC(t)/dt\} = \int_{t_4-t_2} \{I(t)/V(t)\} \quad (9)$$

In Equation 9,  $\int_{t_4-t_2} \{dC(t)/dt\}$  denotes the integration of  $dC(t)/dt$  over the period from time  $t_4$  to time  $t_2$ , and  $\int_{t_4-t_2} \{I(t)/V(t)\}$  denotes the integration of  $I(t)/V(t)$  over the period from time  $t_4$  to time  $t_2$ .

Based on Equation 9, the difference  $\Delta C$  between the capacitance  $C(t_2)$  of the capacitor **11** at time  $t_2$  and the capacitance  $C(t_4)$  of the capacitor **11** at time  $t_4$  is expressed as shown in Equation 10.

$$\begin{aligned}\Delta C &= C(t_2) - C(t_4) \\ &= \int_{t_4-t_2} I(t) / V \\ &= \{Q(t_2) - Q(t_4)\} / V\end{aligned}\quad (10)$$

As is apparent from Equation 10, the capacitance  $C$  of the capacitor **11** varies depending on the timing when the capacitance  $C$  is detected. Thus, the capacitance  $C$  may be detected when stabilized (saturated). In the example illustrated in FIG. 4, the capacitance  $C$  is saturated at time  $t_5$  between times  $t_4$  and  $t_2$ . That is, the capacitance  $C$  is reliably already saturated at least by time  $t_2$ . This is because the terminal voltage  $V$  of the capacitor **11** is maintained at voltage  $VH$  (that is, kept stable) at and after time  $t_4$  as described above.

Thus, in the first embodiment, to detect the capacitance  $C$  utilizing the transient response, the discharge controller **151** starts discharging the capacitor **11** at time  $t_2$ , when the capacitance  $C$  is reliably saturated. This enables the capacitance  $C$  to be accurately detected. In contrast, if the capacitor **11** starts to be discharged, for example, at time  $t_4$ , accurately detecting the capacitance  $C$  is difficult. Furthermore, it is assumed that unlike in the first embodiment, when the capacitance  $C$  is detected, the intermittent charge controller **16** performs intermittent charge control on the capacitor **11**. Even in this case, the capacitance  $C$  varies. Therefore, it is difficult to accurately detect the capacitance  $C$  during the intermittent charge control.

The first embodiment increases the accuracy of detection of the capacitance  $C$  obtained immediately after power-on, by about 10% compared to the conventional art. This enables an increase in the reliability of the results of detection of the capacitance  $C$  and in the lower limit of a reference value (threshold) used to determine that the capacitance  $C$  is abnormal. For example, for a sample of a capacitor having a capacitance  $C$  decreasing to 70% of an initial value thereof when accumulated operation time reaches 70,000 hours, 70% of the initial value is defined as the threshold for determining that the capacitor has come to the end of its life. In this case, the conventional art needs to determine that the capacitor has come to the end of its life when the accumulated operation time reaches 20,000 to 30,000 hours. On the contrary, the first embodiment increases the accuracy of detection of the capacitance  $C$  by 10%, preventing the device from determining that the capacitor has come to the end of its life until the accumulated operation time reaches 40,000 to 60,000 hours.

When the terminal voltage  $V$  reaches  $VL$  or lower, the discharge controller **151** negates the control signal **130** and sets the intermittent charge mode to the on state. Thus, the intermittent charge controller **16** starts the intermittent charge control for intermittently charging the capacitor **11**. In the first embodiment, when the terminal voltage  $V$  of the capacitor **11** reaches a second threshold voltage or lower, the intermittent charge controller **16**, for example, asserts the enable signal **120** via the capacitance detector **15**. In the first embodiment, the second threshold voltage is  $VL$  described above. However, the second threshold voltage may be lower than  $VL$ . In addition, the electronic device may comprise an OR gate configured to OR an enable signal output by the discharge controller **151** and an enable signal output by the intermittent

charge controller **16**. An output signal from the OR gate may be used as the enable signal **210**.

Then, when the terminal voltage  $V$  reaches at least a first threshold voltage higher than the second threshold voltage, the intermittent charge controller **16** negates the enable signal **120**. In the first embodiment, the first threshold voltage is  $VH$ . When the enable signal **120** is negated, the terminal voltage  $V$  falls gradually as a result of the self-discharge of the capacitor **11** as shown in FIG. 2. It is assumed that in this state, for example, at time  $t_{10}$  shown in FIG. 2, the capacitance  $C$  of the capacitor **11** needs to be measured again. In this case, at time  $t_{10}$ , the discharge controller **151** asserts the enable signal **120**, negates the control signal **130**, and sets the intermittent charge mode to the off state.

Thereafter, at time  $t_{11}$ , the terminal voltage  $V$  reaches  $VLH$  again. The timer **153** then measures period  $Thold$ . During period  $Thold$ , the terminal voltage  $V$  reaches  $VH$  and is maintained at  $VH$ . At time  $t_{12}$  shown in FIG. 2, the timer finishes measuring period  $Thold$ . The discharge controller **151** then negates the enable signal **120** and asserts the control signal **130**. Thus, the capacitor **11** starts discharging again.

It is assumed that the terminal voltage  $V$  subsequently reaches voltage  $VL$  at time  $t_{13}$ . Then, the capacitance calculator **154** calculates the capacitance  $C$  of the capacitor **11** based on a period  $Tc'$  from time  $t_{12}$  to time  $t_{13}$ . Period  $Tc'$  corresponds to above-described period  $Tc$ .

[Second Embodiment]

Now, a second embodiment will be described. FIG. 6 is a block diagram showing an exemplary configuration of an electronic device according to the second embodiment. Components in FIG. 6 which are equivalent to corresponding ones in FIG. 1 are denoted by the same reference numbers. The electronic device shown in FIG. 6 differs from that shown in FIG. 1 in that a control unit **14A** is used instead of the control unit **14**. The control unit **14A** comprises an analog-to-digital converter (ADC) **141** and a software module assembly **142**. The analog-to-digital converter **141** digitizes the terminal voltage  $V$  of the capacitor **11**.

The software module assembly **142** comprises a capacitance detector **15** and an intermittent charge controller **16**. The capacitance detector **15** comprises the discharge controller **151**, voltage detector **152**, timer **153**, and capacitance calculator **154** shown in FIG. 1, though these components are not shown in FIG. 6. However, in the second embodiment, not only the discharge controller **151** and the capacitance calculator **154** but also the voltage detector **152** is a software module. Furthermore, the timer **153** is a software timer (that is, a software module). In the second embodiment, the intermittent charge control is also a software module. The intermittent charge controller **16** may be a hardware module as is the case with the first embodiment.

Now, the operation of the second embodiment will be described with reference to FIG. 2 and FIG. 7 taking, as an example, a case where the capacitance  $C$  of the capacitor **11** is detected. FIG. 7 is a flowchart illustrating a procedure for detecting the capacitance  $C$  of the capacitor **11**. First, it is assumed that the capacitance detector **15** functions as the discharge controller **151** (see FIG. 1) at time  $t_0$  in order to detect the capacitance  $C$  of the capacitor **11**. In this case, at time  $t_0$ , the capacitance detector **15** asserts the enable signal **120**, negates the control signal **130**, and sets the intermittent charge controller **16** to the off state (block 701). That is, the capacitance detector **15** sets the power supply device **12** to the on state, sets the discharger **13** to a non-discharge state (discharge off state), and sets the intermittent charge mode to the off state.

Then, the capacitance detector **15** functions as the voltage detector **152** (see FIG. 1) to, for example, periodically determine whether the terminal voltage  $V$  of the capacitor **11** is at least  $VLH$  ( $V \geq VLH$ ) (block **702**). If  $V \geq VLH$  (Yes in block **702**), the capacitance detector **15** functions as the timer **153** (see FIG. 1) to measure a time  $T$  from time  $t1$ , when  $V \geq VLH$  is determined (detected).

Then, the discharge controller **151**, for example, periodically determines whether the measured time  $T$  has reached a predetermined period  $Thold$  or longer ( $T \geq Thold$ ) (block **703**). Here, it is assumed that at time  $t2$ ,  $T \geq Thold$  (Yes in block **703**) as shown in FIG. 2. In this case, the capacitance detector **15** functions as the discharge controller **151** again to negate the enable signal **120**, while asserting the control signal **130** (block **704**). That is, the capacitance detector **15** sets the power supply device **12** to the off state and sets the discharger **13** to a discharge state (discharge on state). At this time, the intermittent charge mode remains off.

Furthermore, the capacitance detector **15** functions as the timer **153** again to measure the time from time  $t2$ , when  $T \geq Thold$  is determined (detected). The capacitance detector **15** simultaneously functions as the voltage detector **152** to, for example, periodically determine whether the terminal voltage  $V$  of the capacitor **11** is equal to or lower than  $VL$  ( $V \leq VL$ ) (block **705**). If  $V \leq VL$  (Yes in block **705**), the capacitance detector **15** obtains the measured period  $Tc$  from time  $t2$  to time  $t3$ , when  $V \leq VL$  is determined (detected) (block **706**).

Then, the capacitance detector **15** functions as the capacitance calculator **154** (see FIG. 1) to calculate the capacitance  $C$  of the capacitor **11** based on the measured period  $Tc$  (block **707**). The capacitance detector **15** then functions as the discharge controller **151** to set the discharger **13** to a discharge off state, while setting the intermediate charge mode to the on state (block **708**). The intermediate charge controller **16** starts the intermediate charge control when the intermediate charge mode is set to the on state.

If the capacitance  $C$  of the capacitor **11** needs to be measured again also during the intermittent charge control, the capacitance detector **15** carries out again the processing starting at block **701** described above. Thus, the second embodiment can use the software module assembly **142** to implement the capacitance detector **15** and the intermittent charge controller **16**.

[Third Embodiment]

Now, a third embodiment will be described. FIG. 8 is a block diagram showing an exemplary configuration of an electronic device according to the third embodiment. Components in FIG. 8 which are equivalent to corresponding ones in FIG. 1 are denoted by the same reference numbers. The electronic device shown in FIG. 8 differs from that shown in FIG. 1 in that a control unit **14B** is used instead of the control unit **14**. The control unit **14B** comprises a capacitance detector **150** and an intermittent charge controller **160**. The capacitance detector **150** comprises a discharge controller **151**, a first voltage detector **152a**, a timer **153**, and a capacitance calculator **154**. Unlike the capacitance detector **15** shown in FIG. 1, the capacitance detector **150** does not comprise a second voltage detector **152b**.

The intermittent charge controller **160** comprises a Schmitt trigger **161**. The Schmitt trigger **161** starts the intermittent charge control when set to the intermittent charge mode. When the terminal voltage  $V$  of the capacitor **11** reaches a second threshold or lower, the Schmitt trigger **161**, for example, asserts the enable signal **120** via the capacitance detector **150**. When the terminal voltage  $V$  reaches a first threshold higher than the second threshold, or higher, the Schmitt trigger **161** negates the enable signal **120**. Thus, the Schmitt trigger **161** has a voltage detection function to detect the first threshold voltage and the second threshold voltage.

Thus, in the third embodiment, the second threshold voltage for the Schmitt trigger **161** is set equal to  $VL$  to allow the Schmitt trigger **161** to act also as the second voltage detector **152b** in the first embodiment. Hence, the Schmitt trigger **161** operates even when not set to the intermittent charge mode, to detect that the terminal voltage  $V$  has reached the second threshold voltage (that is,  $VL$ ) or lower. When not set to the intermittent charge mode, the discharge controller **151** inhibits an output from the Schmitt trigger **161** from being transmitted to the power supply device **12** as the enable signal **120**.

As described above, in the third embodiment, the Schmitt trigger **161** substantially comprises the second voltage detector **152b**. That is, in the third embodiment, the voltage detector **152** comprising the first voltage detector **152a** and the second voltage detector **152b** is present on both the capacitance detector **150** and the intermittent charge controller **160**. The third embodiment can eliminate the need for the dedicated second voltage detector **152b**. Furthermore, the intermittent charge controller **160** comprising the Schmitt trigger **161** allows the terminal voltage  $V$  to be kept at  $VL$  or higher even during the discharge of the capacitor **11**. Thus, the capacitance  $C$  of the capacitor **11** can be detected, with the power supply backup function of the capacitor **11** maintained.

The voltage detector **152** in the first embodiment can be formed of a Schmitt trigger similar to the Schmitt trigger **161** (this Schmitt trigger is hereinafter referred to as the voltage detection Schmitt trigger). In this case, the first threshold for the voltage detection Schmitt trigger may be set equal to  $VLH$ . The second threshold for the voltage detection Schmitt trigger may be set equal to  $VL$ . Furthermore, this voltage detection Schmitt trigger may be applied in the second embodiment. In this case, the voltage detector **152** in the capacitance detector **15** need not be formed of a software module. Thus, the capacitance detector **15** is released from voltage monitoring and can easily measure the capacitance  $C$ . At least one of the above-described embodiments can provide an electronic device having a capacitor and which can accurately detect the capacitance of the capacitor even when the terminal voltage of the capacitor is unstable, as well as a capacitance detection method applied to the electronic device.

The various modules of the systems described herein can be implemented as software applications, hardware and/or software modules, or components on one or more computers, such as servers. While the various modules are illustrated separately, they may share some or all of the same underlying logic or code.

While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions. Indeed, the novel embodiments described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the embodiments described herein may be made without departing from the spirit of the inventions. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the inventions.

What is claimed is:

1. An electronic device comprising:

a capacitor;

a power supplier configured to supply power to the capacitor; and

a controller configured to

saturnate the capacitor by maintaining a terminal voltage of the capacitor for a first time range from a first time to a second time during which first time range the capacitor is reliably saturated,

start a discharge of the capacitor at the second time, and

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calculate a capacitance of the capacitor after starting the discharge, based on the terminal voltage maintained during saturation.

2. The electronic device of claim 1, wherein the controller comprises a discharge controller configured to detect a third time, before the first time, when the terminal voltage reaches a second voltage or higher, the second voltage being lower than a first voltage associated with the power supplier.

3. The electronic device of claim 2, wherein the discharge controller is further configured to stop the discharge effected by the controller when the terminal voltage reaches a third voltage or lower, the third voltage being lower than the second voltage.

4. The electronic device of claim 3, wherein the controller is configured to calculate the capacitance of the capacitor further based on a second time range from starting the discharge to end of the discharge.

5. The electronic device of claim 4, further comprising an intermittent charge controller configured to intermittently charge the capacitor,

wherein the discharge controller is further configured to inhibit operation of the intermittent charge controller at least during a third time range from the third time to the second time.

6. The electronic device of claim 5, wherein the intermittent charge controller is further configured to stop intermittent charge control by detecting that the terminal voltage has reached a first threshold voltage or higher and to start the intermediate charge control by detecting that the terminal voltage has reached a second threshold voltage or lower, the second threshold voltage being lower than the first threshold voltage.

7. The electronic device of claim 6, further comprising:  
a first voltage detector configured to detect that the terminal voltage is the second voltage or higher; and  
a second voltage detector configured to detect that the terminal voltage is the third voltage or lower,  
wherein the discharge controller is further configured to detect a fourth time range from the third time, when the first voltage detector detects that the terminal voltage is the second voltage or higher, to at least the second time, and to stop the discharge when the second voltage detector detects that the terminal voltage is the third voltage or lower.

8. The electronic device of claim 7, wherein:  
the second threshold voltage is equal to the third voltage;  
the intermittent charge controller comprises a Schmitt trigger configured to detect that the terminal voltage is the third voltage or lower; and  
the Schmitt trigger comprises the second voltage detector.

9. The electronic device of claim 6, wherein the first threshold voltage is equal to the first voltage.

10. The electronic device of claim 1, wherein the first time is a time when the capacitance of the capacitor initially becomes saturated.

11. A method for determining a capacitance of a capacitor configured to receive power from a power supplier, wherein the method comprises:

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saturation of the capacitor by maintaining a terminal voltage of the capacitor for a first time range from a first time to a second time during which first time range the capacitor is reliably saturated;

starting a discharge of the capacitor at the second time; and  
calculating a capacitance of the capacitor after starting the discharge, based on the terminal voltage maintained during the saturation.

12. The method of claim 11, further comprising detecting a third time, before the first time, when the terminal voltage reaches a second voltage or higher, the second voltage being lower than a first voltage associated with the power supplier.

13. The method of claim 12, further comprising stopping the discharge when the terminal voltage reaches a third voltage or lower, the third voltage being lower than the second voltage.

14. The method of claim 13, wherein calculating the capacitance of the capacitor is further based on a second time range from starting the discharge to end of the discharge.

15. The method of claim 14, wherein:

the electronic device further comprises an intermittent charge controller configured to intermittently charge the capacitor; and

the method further comprises inhibiting operation of the intermittent charge controller at least during a third time range from the third time to the second time.

16. The method of claim 15, further comprising:  
stopping intermittent charge control by detecting that the terminal voltage has reached a first threshold voltage or higher; and

starting the intermediate charge control by detecting that the terminal voltage has reached a second threshold voltage or lower, the second threshold voltage being lower than the first threshold voltage.

17. The method of claim 16, further comprising:  
detecting that the terminal voltage is the second voltage or higher;  
detecting that the terminal voltage is the third voltage or lower;  
detecting a fourth time range from the third time, when the terminal voltage is detected to be equal to or higher than the second voltage, to the first time or more; and  
stopping the discharge when a state where the terminal voltage is detected to be the third voltage or lower.

18. The method of claim 17, wherein:  
the second threshold voltage is equal to the third voltage;  
the intermittent charge controller comprises a Schmitt trigger; and  
the terminal voltage is detected by the Schmitt trigger as the third voltage or lower.

19. The method of claim 16, wherein the first threshold voltage is equal to the first voltage.

20. The method of claim 11, wherein the first time is a time when the capacitance of the capacitor initially becomes saturated.

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